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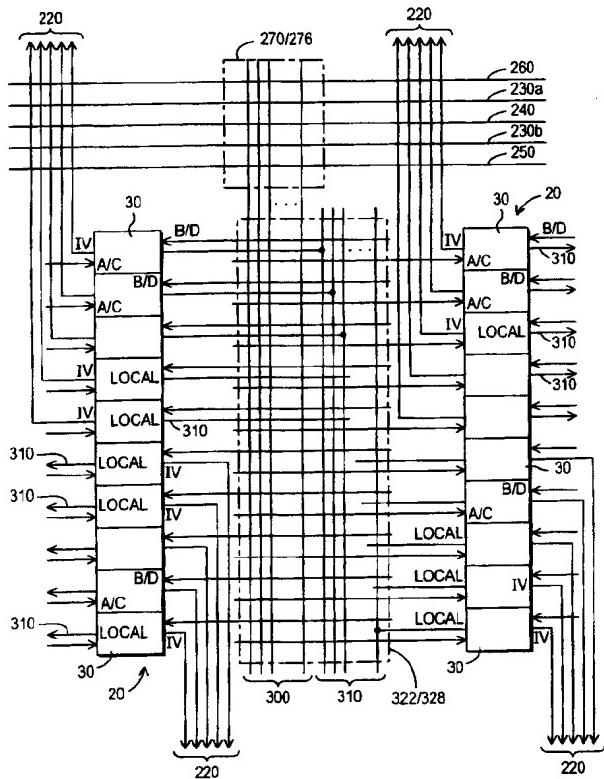
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**(54) Title: INTERCONNECTION RESOURCES FOR PROGRAMMABLE LOGIC INTEGRATED CIRCUIT DEVICES**



**(57) Abstract:** A programmable logic device has many regions of programmable logic, together with relatively general-purpose, programmable, interconnection resources that can be used to make interconnections between virtually any of the logic regions. In addition, various types of more local interconnection resources are associated with each logic region for facilitating the making of interconnections between adjacent or nearby logic regions without the need to use the general-purpose interconnection resources for those interconnections. The local interconnection resources support flexible clustering of logic regions via relatively direct and therefore high-speed interconnections, preferably in both horizontal and vertical directions in the typically two-dimensional array of logic regions. The logic region clustering options provided by the local interconnection resources are preferably boundary-less or substantially boundary-less within the array of logic regions.

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INTERCONNECTION RESOURCES FOR  
PROGRAMMABLE LOGIC INTEGRATED  
CIRCUIT DEVICES

Background of the Invention

5        This invention relates to programmable logic array integrated circuit devices ("programmable logic devices" or "PLDs"), and more particularly to interconnection resources for use on programmable logic devices that increase the speed at which those devices  
10      can be made to operate.

Programmable logic devices typically include (1) many regions of programmable logic, and (2) programmable interconnection resources for selectively conveying signals to, from, and/or between those logic  
15      regions. Each logic region is programmable to perform any of several different, relatively simple logic functions. The interconnection resources are programmable to allow the logic regions to work together to perform much more complex logic functions

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than can be performed by any individual logic region. Examples of known PLDs are shown in Wahlstrom U.S. patent 3,473,160, Freeman U.S. patent Re. 34,363, Cliff et al. U.S. patent 5,689,195, Cliff et al. U.S. patent 5,909,126, and Jefferson et al. U.S. patent application No. 09/266,235, all which are hereby incorporated by reference herein.

A frequent objective in the design of PLDs is to increase the speed at which the device can be operated. The speeds at which signals can travel through the interconnection resources between logic regions is particularly important to determining device speed. Overall, the interconnection resources must have the general-purpose capability of connecting any logic region to any other logic region. But in addition to this, it can be helpful to find ways to make faster interconnections between nearby logic regions. Many complex logic tasks can be broken down into parts, each of which can be performed by a respective cluster of logic regions. By providing interconnection resources that facilitate the flexible formation of clusters of logic regions with high-speed interconnection capabilities among the logic regions in such clusters, the ability of the PLD to perform various complex logic tasks at high speed is enhanced.

In view of the foregoing, it is an object of this invention to provide improved interconnection resources for programmable logic devices.

It is a more particular object of this invention to provide interconnection resources for programmable logic devices that facilitate the formation of extended clusters of nearby logic modules between which high-speed interconnections can be made.

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Summary of the Invention

These and other objects of the invention are accomplished in accordance with the principles of the invention by providing programmable logic devices with interconnection resources that facilitate the provision of interconnections between logic modules in adjacent rows of logic regions, as well as between nearby logic regions in each row. Typically the logic regions on a PLD are arranged in a two-dimensional array of intersecting rows and columns of such regions. Each logic region may include a plurality of subregions. Local feedback conductors may be provided for facilitating communication among the subregions in a region. In addition, these local feedback conductors may be interleaved between horizontally adjacent regions in a row, thereby facilitating high speed interconnection among the subregions of horizontally adjacent regions. In accordance with this invention such high speed local interconnection is additionally provided between adjacent rows in any of several ways. For example, output signals of subregions in each row may be additionally applied substantially directly (i.e., without making use of the more general-purpose interconnection resources of the device) to programmable logic connectors (e.g., multiplexers) feeding output drivers that are otherwise normally or nominally associated with subregions in an adjacent row. This makes it possible for the subregions in one row to optionally drive interconnection resources that are normally associated with an adjacent row, thereby facilitating clustering of logic regions in adjacent rows. As an alternative or addition to the foregoing, the interconnection resources that bring signals into

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the regions in each row can be partly shifted or extended relative to the rows so that some signals can be more readily and directly brought into each row from the adjacent rows, again without having to make use of  
5 the more general-purpose interconnection resources of the device. This again facilitates forming clusters of logic regions in adjacent rows. As still another alternative, the interconnection resources that bring signals into each row can be substantially directly  
10 driven by signals from similar resources in another row, thereby again facilitating the formation of clusters of logic regions in adjacent rows without needing to use the general-purpose interconnection resources.

15 As an alternative or addition to the foregoing, clustering of logic regions along a row may be facilitated by providing conductors associated with each logic region that extend adjacent a relatively small subplurality of the other adjacent logic regions  
20 in that row. For example, one of these conductors associated with each logic region may extend to the left from that logic region adjacent a relatively small number of other logic regions to the left of the associated logic region, and another of these  
25 conductors may extend to the right by approximately the same number of other logic regions. The same signal or different signals from the associated logic region can be applied to each of these conductors, and thereby to the other logic regions that these conductors are  
30 adjacent to. (The signals on these conductors can alternatively come from other sources.) The relatively short length, light loading, and other similar characteristics of these conductors make them especially suitable for use in providing high-speed

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interconnections from the associated logic region (or other signal source(s)) to the other logic regions that they are adjacent to, thereby again facilitating flexible clustering of nearby logic regions.

5       Further features of the invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

Brief Description of the Drawing

10       FIG. 1 is a simplified schematic block diagram of relevant portions of an illustrative programmable logic device constructed in accordance with this invention.

15       FIG. 2 is a more detailed, but still simplified, schematic block diagram of a representative portion of the programmable logic device shown in FIG. 1.

20       FIG. 3 is a more detailed, but still simplified, schematic block diagram of an illustrative embodiment of another representative portion of the device shown in FIG. 1.

25       FIG. 4 is a simplified schematic block diagram of a representative portion of an alternative embodiment of certain aspects of the FIG. 1 device in accordance with the invention.

30       FIG. 5 is a simplified schematic block diagram of a representative portion of another alternative embodiment of certain aspects of the FIG. 1 device in accordance with the invention.

35       FIG. 6 is a more detailed, but still simplified, schematic block diagram of an illustrative embodiment of another representative portion of the FIG. 1 device in accordance with the invention.

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FIG. 7 is a more detailed, but still simplified, schematic block diagram of an illustrative embodiment of still another representative portion of the FIG. 1 device in accordance with the invention.

5 FIG. 8 is a more detailed, but still simplified, schematic block diagram of an illustrative embodiment of yet another representative portion of the FIG. 1 device in accordance with the invention.

10 FIG. 9 is a simplified block diagram of an illustrative system employing a programmable logic device in accordance with the invention.

Detailed Description of the Preferred Embodiments

Although the principles of this invention are equally applicable to many different programmable logic device architectures, the invention will be fully understood from the following explanation of its application to programmable logic devices of the type shown in commonly assigned, co-pending, U.S. patent application No. \_\_\_\_\_, filed \_\_\_\_\_  
15 (Docket No. 174/172), which is hereby incorporated by reference herein in its entirety. Because the last-mentioned reference is incorporated by reference herein, it will not be necessary to actually repeat the content of that reference here. Where elements  
20 described in that reference are mentioned again here, the same reference numbers will be used here to the greatest extent possible, even though such elements may be here diagrammed more simply or described more briefly.  
25

30 FIG. 1 (similar to FIG. 2 in the last-mentioned reference) shows the presently relevant portion of an illustrative programmable logic device 10 constructed in accordance with this invention.

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Device 10 includes several rows of regions 20 of programmable logic, each of which includes a plurality of subregions 30 of programmable logic. To avoid overcrowding the drawing, individual subregions 30 are  
5 delineated only in the extreme upper left-hand region 20 in FIG. 1. The rows of logic regions 20 are interspersed with rows of input/output ("I/O") circuitry 40. At the extreme top and bottom of the circuitry shown in FIG. 1 are rows of memory  
10 regions 50, which the user of device 10 can use as RAM, ROM, product-term logic, content addressable memory, etc. Regions 60 include phase-locked loop circuitry, region 70 includes control logic and pins, region 80 includes JTAG logic and pins, and region 120 is part of  
15 a secondary signal distribution network. The details of regions 40, 60, 70, 80, and 120 are of little interest in connection with this invention and therefore need not be significantly described herein.

Associated with each row of logic regions 20  
20 is a plurality of global horizontal interconnection conductors 230a/b. (The "a/b" designation is from the last-mentioned reference and refers to "a" conductors having "normal" signal propagation speed characteristics and "b" conductors having higher signal propagation speed characteristics. This feature is at most only tangential to the present invention and therefore need not be further detailed herein.) Also associated with the left and right half of each row of logic regions 20 is a plurality of so-called direct  
25 horizontal interconnection conductors 240. Still further associated with subsets of horizontally adjacent regions 20 in each row are groups of so-called horizontal network of fast line ("HNFL")  
30 interconnection conductors 250.

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Associated with each column of logic regions 20 (and extending across I/O regions 40 and into memory regions 50) is a plurality of global vertical interconnection conductors 200a/b. (Again, 5 the "a/b" designation is from the last-mentioned reference and refers to some conductors 200a having normal speed and other conductors 200b having higher speed.) Associated with the upper and lower half of each column of logic regions 20 (and the associated I/O 10 and memory circuitry 40 and 50) is a plurality of so-called half vertical interconnection conductors 210a/b. (Once again, the "a/b" designation refers to different conductors having different signal propagation speed characteristics.) Associated with vertically adjacent 15 pairs of regions 20 and 50 are pluralities of so-called interleaved vertical ("IV") interconnection conductors 220. These conductors 220 form at least part of a first illustrative embodiment of this invention.

20 It will be understood that FIG. 1 shows only a few representative ones of each of the various types of interconnection conductors mentioned above.

FIG. 2 shows selected circuitry associated with two, representative, horizontally adjacent logic 25 regions 20 in a typical row of such regions. The circuitry shown in FIG. 2 includes selected circuitry for supplying signals to the subregions 30 in the depicted regions 20, and selected circuitry for conveying signals from those subregions. Note that 30 between the depicted regions are a plurality of region-feeding conductors 300 and a plurality of local feedback conductors 310. Signals on the conductors 230a/b, 240, 250, and 260 associated with the row that includes depicted regions 20 can be applied to region-

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feeding conductors 300 via programmable logic connector ("PLC") and driver circuitry 270/276. Circuitry 270/276 may be constructed as shown in FIG. 3 of the last-mentioned reference (see also FIG. 7 herein).

5 Local feedback conductors 310 are supplied with the so-called LOCAL output signals of selected ones of the depicted subregions 30. In particular, half of the subregions 30 in each depicted region 20 supply their LOCAL output signals to the local feedback conductors  
10 310 between those regions. (The LOCAL output signals of the other subregions go to local feedback conductors to the left or right of the representative circuitry shown in FIG. 2.) Signals on depicted conductors 300/310 can be applied to subregion input terminals A-D  
15 via PLC circuitry 322/328. Circuitry 322/328 may be constructed as shown in FIG. 4 of the last-mentioned reference. Two of the four main data input signals A-D of each of the depicted subregions come from the conductors 300/310 and circuitry 322/328 to the right  
20 of that subregion, and the other two of those inputs come from the elements 300/310/322/328 to the left of that subregion. In particular, the B and D inputs to each subregion 30 come from the right, and the A and C inputs to each subregion 30 come from the left.

25 Each subregion 30 may be constructed as shown in FIGS. 5A and 5B of the last-mentioned reference. Thus each subregion 30 may include (among other components) a four-input look-up table or other combinatorial logic circuitry for producing an  
30 intermediate signal which is any logical combination of the four main data inputs A-D to the subregion. Each subregion 30 may further include a register for registering the intermediate signal, and PLC circuitry for outputting either the intermediate signal or the

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register output signal as any of a LOCAL output signal 310, an interleaved vertical ("IV") output signal 220, and/or two more global output signals (not shown in FIG. 2, but shown as OUT0 and OUT1 in FIG. 3. In 5 particular, any of the above-mentioned four outputs of a subregion 30 can be separately selected to be either the intermediate signal or the register output signal of that subregion.

FIG. 2 also shows that the IV outputs 220 of 10 half the subregions 30 on the left and half the subregions 30 on the right extend upwardly (to the row of regions 20 above the row shown in part in FIG. 2), and that the IV outputs 220 of the other half of the subregions on the left and right extend downwardly (to 15 the row of regions 20 below the row shown in part in FIG. 2). The particular pattern for the IV outputs to go up and down can be different from that shown in FIG. 2 if desired. For example, whereas FIG. 2 shows that the IV outputs of the upper half of the 20 subregions 30 go up, and the IV outputs of the lower half of the subregions go down, a different pattern is suggested in FIG. 3, which shows the IV outputs 220 of vertically alternating subregions 30 going up and down. The same is true for the left-right patterns of LOCAL 25 outputs shown in FIG. 2. That is, a different pattern of LOCAL outputs can be used instead of the pattern shown in FIG. 2 in which the upper half of the subregions 30 in each region 20 have their LOCAL outputs going to the right and the lower half have 30 their outputs going to the left. An example of a different pattern would be to have vertically alternating subregions going to the left and right in terms of LOCAL output.

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FIG. 3 shows circuitry 500 associated with four representative subregions 30 (two subregions in each of two horizontally adjacent regions 20), principally for applying the output signals of those 5 subregions to adjacent horizontal and vertical conductors and for making interconnections between adjacent horizontal and vertical conductors (e.g., so that signals can turn from horizontal to vertical conductors or vice versa). FIG. 3 is similar to FIG. 6 10 in the last-mentioned reference. Much of what is shown in FIG. 3 is not especially important to the present invention. Those unimportant or relatively unimportant portions of FIG. 3 will therefore not be described in full detail herein, it being appreciated that the last- 15 mentioned reference provides a full discussion (in connection with FIG. 6 of the last-mentioned reference) of all portions of this FIG. that are not described here. In addition, operation of portions of FIG. 3 that are not specifically described here can generally 20 be inferred from the portions that are described.

The portions of FIG. 3 that are germane to the present invention are those that are associated with the two conductors 220 shown in that FIG. Initially it should be said that one of the 25 conductors 220 shown in FIG. 3 comes from the IV output of a subregion 30 in the row above the row shown in part in that FIG., and the other of those two conductors 220 comes from the IV output of a subregion 30 in the row below the row shown in part in 30 FIG. 3. (Although the representative circuitry shown in FIG. 3 includes four subregions 30, producing four IV output signals 220, the FIG. 3 circuitry only receives two IV input signals 220. This does not mean, however, that there is a net excess of IV outputs. The

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explanation for this is that there is additional similar driver circuitry 500 to the left/right of what is shown in FIG. 3 which utilizes the IV outputs that would appear to be excess if only a vertical slice like 5 what is shown in FIG. 3 is considered.)

Both of the IV input signals 220 to the circuitry shown in FIG. 3 are among the inputs to PLC 522. One of the IV input signals 220 to the circuitry shown in FIG. 3 is among the inputs to three 10 out of six PLCs 502, 506, 530, 540, 560, and 564. The other IV input signal 220 to FIG. 3 is among the inputs to the other three out of the six just-mentioned PLCs.

Other inputs to PLC 522 are (1) the signal from an adjacent global vertical conductor 200b, (2) 15 the signal from an adjacent half vertical conductor 210b, (3) one of the global output signals ("OUT1") of the upper left-hand subregion 30, (4) one of the global output signals ("OUT0") of the lower right-hand subregion 30, (5) one of the global output signals 20 ("OUT1") of the lower left-hand subregion 30, (6) one of the global output signals ("OUT0") of the upper right-hand subregion 30, and (7) the signal from a selected one of four adjacent global vertical conductors 200a. (PLC 520 makes the one-of-four 25 selection referred to at the end of the preceding sentence.)

PLC 522 is programmable (e.g., by 30 programmable function control elements ("FCEs") that are not shown in FIG. 3, but that are like FCE 526 shown in FIG. 3 for controlling tri-state driver 524) to select any one of its input signals as its output signal. The output signal of PLC 522 is applied to tri-state driver 524. If tri-state driver 524 is enabled by the associated FCE 526, driver 524 amplifies

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the signal it receives and applies the resulting amplified signal to one of the adjacent fast or high-speed global horizontal conductors 230b. (If tri-state driver 524 is not thus enabled by the associated FCE 5 526, the driver is off and looks like a high impedance to the associated conductor 230b.)

From the foregoing it will be seen that application to PLC 522 of IV output signals from the row above and the row below allows PLC 522 and its 10 associated tri-state driver 524 to be used to apply one of those IV signals from an adjacent row to a global horizontal conductor 230b associated with the row partly shown in FIG. 3. In that way a subregion 30 in the row above or below the partly depicted row can 15 effectively "steal" elements 522 and 524 from the partly depicted row and thereby become (for at least the purposes served by elements 522 and 524) like a subregion in the depicted row. Elements 220, 522, and 524 therefore allow a subregion 30 in an adjacent row 20 to provide very direct drive to one of the conductors 230b in the partly depicted row. Although other elements in the partly depicted row could be driven by this type of IV signal routing, in the particularly preferred embodiment shown this IV routing is very 25 high-speed by virtue of being through relatively large and strong tri-state driver 524 to a high-speed conductor 230b. From conductor 230b a signal can get to any of the regions 20 in the row served by that conductor.

30 Other possible routings of the IV signals 220 provided by the FIG. 3 circuitry will now be discussed.

As has been mentioned, one of the two IV signals received by the FIG. 3 circuitry from the two adjacent rows is applied to one input terminal of

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PLC 530. PLC 530 can select this IV signal input in lieu of any of its other inputs for application to buffer 532. The output signal of buffer 532 is applied to PLC 534 (e.g., a demultiplexer). PLC 534 is 5 programmable to apply its input signal to any one or more of two of the adjacent normal-speed global horizontal conductors 230a and one of the adjacent normal-speed half vertical conductors 210a.

The PLC 540 routing of one of the received IV 10 signals 220 is similar to that just described for PLC 530, except that in the case of routing via elements 540, 542, and 544, one of the possible destinations is one of the adjacent normal-speed global vertical conductors 200a.

The PLC 502 routing of one of the received IV 15 signals 220 allows that IV signal to be applied to inverting buffer 504 in lieu of the other inputs to PLC 502. The output signal of buffer 504 is applied to one of the adjacent HNFL conductors 250 that extends to 20 the left adjacent several other logic regions 20 from the circuitry shown in FIG. 3. The same IV signal 220 is also applied to one input terminal of PLC 560. PLC 560 can select that signal for application to inverting buffer 562 and thereby to another adjacent 25 HNFL conductor 250 that extends to the right adjacent several other logic regions 20 from the circuitry shown in FIG. 3. Thus the IV signal being discussed can be applied to a leftward extending HNFL conductor 250, a rightward extending HNFL conductor 250, or to both of 30 those conductors. As is described in more detail below in connection with FIG. 6, HNFL conductors 250 provide relatively high-speed communication -- from the associated source logic region(s) 20 to any of the logic regions 20 that they pass adjacent to -- because

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of the relatively short length, light loading, etc., of the HNFL conductors.

The PLC 506 and PLC 564 IV signal routing is similar to that described for PLCs 502 and 560, except 5 that the other of the two IV signals 220 received by the FIG. 3 circuitry is applied to PLCs 506 and 564, and different HNFL conductors 250 are driven by inverting buffers 508 and 566.

From the foregoing, it will be seen that the 10 IV connections 220 between adjacent rows of logic regions 20 facilitate flexible formation of clusters of logic regions or subregions, as well as relatively high-speed communication within such clusters. For example, using an IV connection 220 and routing via 15 elements like 522 and 524, a subregion 30 in one row can be clustered with (i.e., relatively directly coupled to) any of the subregions in one of the adjacent rows. The same is true (albeit using somewhat slower, normal-speed global horizontal conductors 230a) 20 via elements 530/532/534 or 540/542/544. As another example, using an IV connection 220 and routing via elements like 502, 506, 560, and/or 564, a subregion 30 in one row can be clustered with any of the logic 25 regions 20 in an adjacent row served by the associated HNFL conductors 250 in the adjacent row. In addition to providing more direct, and therefore higher speed interconnections between adjacent rows, the provision of IV conductors 220 reduces the need to use longer-haul and more general-purpose vertical conductors 200 30 and 210 for inter-row connections. This helps to reduce the numbers of conductors 200 and 210 that must be provided on the device.

It should be noted that the clustering options afforded by the above-described IV circuitry

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are preferably boundary-less within the array of logic regions 20. By this it is meant that any logic region 20 can serve as a member of a cluster, and the cluster can extend from that logic region in substantially the 5 same way regardless of the logic region that is chosen as the cluster member being considered. Only the physical edges of the logic region array bound the possible clusters.

An alternative embodiment of the invention 10 which facilitates flexible clustering of subregions 30 in one row with logic regions 20 (and their subregions 30) in another adjacent row is shown in FIG. 4. Although for clarity FIGS. 2 and 3 show the horizontal interconnection conductors 230/240/250/260 15 associated with a typical row laterally displaced from the other circuitry of that row, FIG. 1 is somewhat less schematic more physically accurate in that it shows the horizontal conductors and other circuitry of each row super-imposed on or interspersed with one 20 another. FIG. 4 shows the horizontal conductors 230/240/250/260 in the same super-imposed or interspersed way.

In FIG. 4 the horizontal conductors 230/240/250/260 associated with each row are shown 25 subdivided into three laterally spaced subsets, each of which preferably includes some of each type of conductor (especially some of each of conductors 230, 240, and 250). FIG. 4 further shows the PLCs 270/276 nominally associated with each row and each group of 30 logic region feeding conductors 300 shifted vertically relative to the associated row so that some of the inputs to those PLCs come from the horizontal conductors 230/240 etc. associated with one of the rows that is adjacent to the row with which the PLCs 270/276

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are nominally associated. Considering, for example, the left-most logic region 20 shown in row N in FIG. 4, the PLCs 270/276 that feed the conductors 300 to the left of that logic region receive their inputs from the 5 lower two subsets of the horizontal conductors 230/240 etc. associated with row N and from the upper-most subset of the horizontal conductors 230/240 etc. associated with the row below row N (i.e., row N+1). This arrangement makes it possible to feed signals from 10 row N+1 to any of the subregions 30 in the exemplary region 20 being discussed very directly and without having to make use of the vertical interconnection resources (e.g., elements 200/210) of the device.

Similarly, the PLCs 270/276 that feed the 15 conductors 300 to the right of the left-most logic region 20 shown in row N in FIG. 4 receive their inputs from the upper two subsets of the horizontal conductors 230/240 etc. associated with row N and from the lower-most subset of the horizontal 20 conductors 230/240 etc. associated with the row above row N (i.e., row N-1). This makes it possible to feed signals from row N-1 to any of the subregions 30 in the logic region 20 being discussed very directly and without having to use the other vertical 25 interconnection resources (e.g., elements 200/210) of the device.

It should be noted that because each PLC group 270/276 is interleaved between two logic regions 20 (one region to the left and one region to 30 the right) as is described more fully above in connection with FIG. 2, the inputs to each group 270/276 from the adjacent row are available to both regions 20 served by that group 270/276 and its associated conductors 300.

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A possible alternative to shifting the groups of PLCs 270/276 as shown in FIG. 4 is shown in FIG. 5. In the FIG. 5 alternative at least some of the region-feeding conductors 300 interleaved between each 5 horizontally adjacent pair of logic regions 20 in each row extend into the row above or below that row for programmably selectable connection to the horizontal conductors 230/240/250/260 associated with that other row. Considering, for example, the conductors 300a 10 that serve any two adjacent logic regions 20 in the upper row ("row N") in FIG. 5, those conductors 300a can receive signals (via PLCs 270/276) from both the conductors 230/240/250/260 associated with row N and the conductors 230/240/250/260 associated with the row 15 below row N (i.e., "row N+1"). Similarly, the conductors 300b that serve any two adjacent logic regions 20 in row N+1 in FIG. 5 can receive signals (via PLCs 270/276) from both the conductors 230/240/250/260 associated with row N+1 and the 20 conductors 230/240/250/260 associated with row N. The interconnection arrangement described above for rows N and N+1 can be continued to other adjacent rows (e.g., as shown by the dotted line conductors 300c and the dotted extensions of conductors 300a extending from row 25 N to row N-1 (not shown), and as shown by the dotted line conductors 300d and the dotted extensions of conductors 300b extending from row N+1 to row N+2 (not shown)).

Like the arrangements shown in earlier FIGS., 30 arrangements of the type shown in FIG. 5 facilitate direct clustering of a logic region 20 in one row with logic regions in an adjacent row without the need to use other vertical interconnection resources such as elements 200 and 210 to provide inter-row

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communication. Also, like the arrangements shown in earlier FIGS., the clustering options afforded by FIG. 5 are high-speed and flexible (e.g., they can be essentially boundary-less within the array of logic 5 regions 20).

The HNFL conductors 250 that have already been occasionally mentioned also facilitate flexible clustering of logic regions 20 without recourse to the general interconnection conductor resource network in 10 accordance with this invention. Accordingly the HNFL conductors will now be considered in more detail in connection with FIGS. 6 and 7.

FIG. 6 shows that typical HNFL conductors 250 originate at a driver block 500 (FIG. 3) associated 15 with a horizontally adjacent pair of logic regions 20 and extend, respectively, to the left and right of the source logic regions by a relatively small (but preferably plural) number of other logic regions. For example, each HNFL conductor 250 may extend four or 20 five logic regions 20 to the left or right of the source logic regions. The possible sources of the signals on HNFL conductors 250 have been described above in connection with FIG. 3. PLC groups 270/276 (shown in more detail in FIG. 7 and described in more 25 detail below in connection with that FIG.), associated with the region-feeding conductors 300 between at least some of the horizontally adjacent logic regions 20 that the HNFL conductors 250 pass, can apply the HNFL conductor signals to those region-feeding conductors 30 for application to the logic regions on either side of those conductors 300. FIG. 6 shows the PLC groups 270/276 associated with only every other region-feeding conductor group 300 being able to make such connections from the HNFL conductors 250. This helps

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reduce the loading on the HNFL conductors, thereby helping to increase the operating speed of those conductors. As an alternative, however, all PLC groups 270/276 may have the capability of making 5 connections from the HNFL conductors.

As has been mentioned, FIG. 7 shows a representative PLC group 270/276 in more detail. FIG. 7 is similar to FIG. 3 in the last-mentioned reference. Accordingly, only the portion of FIG. 7 10 that is particularly pertinent to the present invention will be described in full detail herein. FIG. 7 shows that one or more of the HNFL conductors served by a PLC 276 can be applied to input terminals of that PLC. PLC 276 is programmable (by FCEs that are not shown but 15 that can be similar to FCEs 272) to apply any one of its inputs to inverting buffer 278 and thereby to a region-feeding conductor 300. To increase the speed with which an HNFL conductor signal can reach region-feeding conductor 300, the HNFL conductor(s) are 20 connected substantially directly to relatively small, downstream PLC 276, thereby effectively bypassing upstream PLCs 270 (which can select signals from other conductors 230, 240, and 260 associated with the row that includes PLCs 270/276).

25 To briefly recapitulate the foregoing discussion of HNFL conductors 250, these conductors facilitate flexible high-speed clustering of nearby logic regions due to such characteristics as the following: (1) there is only a single source for the 30 signal on each HNFL conductor (i.e., the driver block 500 associated with the pair of logic regions 20 near the midpoint of a left- and right-extending pair of HNFL conductors 250), (2) the HNFL conductors are relatively short, (3) the HNFL conductor signals are

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applied to region-feeding conductors 300 via downstream PLCs 276 that bypass other upstream PLCs 270, and  
(4) the PLC groups 270/276 connect the HNFL conductors to only certain groups of region-feeding  
5 conductors 300 that the HNFL conductors pass.

From FIG. 3 and the earlier discussion of that FIG. it will be appreciated that each leftwardly extending HNFL conductor 250 is effectively paired with a rightwardly extending conductor 250. Both conductors 10 in each such pair can be driven by the same signal, or different signals can be applied to each conductor in any pair. The sources of the HNFL signals are subregion 30 output signals, interleaved conductor 220 signals, and fast vertical interconnection 15 conductor 210b signals.

FIG. 8 shows an illustrative embodiment of another type of conductor arrangement that facilitates flexible, close, and direct (i.e., high-speed) association of nearby logic regions 20 without having 20 to make use of the more general interconnection resources of the device. In this embodiment at least some of the region-feeding conductors 300 interleaved between each horizontally adjacent pair of logic regions 20 in the center row have relatively direct 25 programmable connections 276a to at least some of the region-feeding conductors 300 interleaved between the logic regions above and below the first-mentioned logic regions. Similarly, at least some of the local feedback conductors 310 interleaved between each 30 horizontally adjacent pair of logic regions 20 in the center row have relatively direct programmable connections 276b to at least some of the region-feeding conductors 300 interleaved between the logic regions above and below the first-mentioned logic regions.

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Programmable connections 276a and 276b may be additional inputs to downstream (and therefore relatively fast) PLCs 276 in FIG. 7. Alternatively, connections 276a and 276b may be programmably controlled (e.g., by FCEs) pass gates or transistors between the conductors 300/310 associated with those connections 276a/276b. Such pass gates or transistors are also sometimes referred to herein as PLCs.

Connections 276a allow a signal applied to a region-feeding conductor 300 associated with the center row (e.g., from any of the conductors 230/240/250/260 associated with the center row) to be applied not only to the center row logic regions 20 to the left and/or right of that conductor 300, but also to the adjacent logic regions 20 above and/or below those logic regions (i.e., in the adjacent rows above and below the center row). Similarly, connections 276b allow a signal applied to a local feedback conductor 310 associated with the center row (i.e., from the associated subregion 30 in a region to the left or right of that conductor 310) to be applied not only to the center row logic regions to the left and/or right of that conductor 310, but also to the adjacent logic regions 20 above and/or below those logic regions (i.e., in the adjacent rows above and below the center row).

Connections 276a and 276b therefore facilitate rapid and close association of logic regions that are generally vertically adjacent to one another. For example, connections 276a facilitate application of the same signals (from the conductors 230/240/250/260 associated with the center row) to vertically adjacent logic regions 20. Connections 276b facilitate application of signals from center row logic regions 20 to other vertically adjacent logic regions 20.

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Although both types of connections 276a and 276b are shown in FIG. 8, it will be understood that only one of these two types of connections may be provided, with the other type being omitted.

- 5 Similarly, the numbers and patterns of conductors 300/310 that have connections 276a and/or 276b may be varied as desired. Whereas FIG. 8 only shows signals flowing from center row conductors 300/310 to vertically adjacent row conductors 300, it will be  
10 understood that similar connections can be provided for allowing signal flow in the opposite direction or in other patterns or ways between vertically adjacent rows.

FIG. 9 illustrates a programmable logic device 10 of this invention in a data processing system 1002. Data processing system 1002 may include one or more of the following components: a processor 1004; memory 1006; I/O circuitry 1008; and peripheral devices 1010. These components are coupled together by a  
20 system bus 1020 and are populated on a circuit board 1030 which is contained in an end-user system 1040.

System 1002 can be used in a wide variety of applications, such as computer networking, data networking, instrumentation, video processing, digital  
25 signal processing, or any other application where the advantage of using programmable or reprogrammable logic is desirable. Programmable logic device 10 can be used to perform a variety of different logic functions. For example, programmable logic device 10 can be configured  
30 as a processor or controller that works in cooperation with processor 1004. Programmable logic device 10 may also be used as an arbiter for arbitrating access to a shared resource in system 1002. In yet another example, programmable logic device 10 can be configured

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as an interface between processor 1004 and one of the other components in system 1002. It should be noted that system 1002 is only exemplary, and that the true scope and spirit of the invention should be indicated 5 by the following claims.

Various technologies can be used to implement programmable logic devices 10 having the features of this invention, as well as the various components of those devices (e.g., the above-described PLCs and the 10 FCEs that control the PLCs). For example, each PLC can be a relatively simple programmable connector such as a switch or a plurality of switches for connecting any one of several inputs to an output. Alternatively, each PLC can be a somewhat more complex element which 15 is capable of performing logic (e.g., by logically combining several of its inputs) as well as making a connection. In the latter case, for example, each PLC can be product term logic, implementing functions such as AND, NAND, OR, or NOR. Examples of components suitable for implementing PLCs are EPROMs, EEPROMs, 20 pass transistors, transmission gates, antifuses, laser fuses, metal optional links, etc. As has been mentioned, the various components of PLCs can be controlled by various, programmable, function control 25 elements ("FCEs"). (With certain PLC implementations (e.g., fuses and metal optional links) separate FCE devices are not required.) FCEs can also be implemented in any of several different ways. For example, FCEs can be SRAMs, DRAMs, first-in first-out 30 ("FIFO") memories, EPROMs, EEPROMs, function control registers (e.g., as in Wahlstrom U.S. patent 3,473,160), ferro-electric memories, fuses, antifuses, or the like. From the various examples mentioned above it will be seen that this invention is applicable to

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both one-time-only programmable and reprogrammable devices.

It will be understood that the forgoing is only illustrative of the principles of the invention, and that various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention. For example, the numbers of the various types of resources on device 10 can be different from the numbers present in the depicted and described illustrative embodiments. This applies to such parameters as the numbers of rows and columns of the various types of circuitry, the number of subregions 30 in each region 20, the numbers of the various types of interconnection conductors, the numbers and sizes of the PLCs provided for making interconnections between various types of interconnection conductors, etc. It will also be understood that various directional and orientational terms such as "vertical" and "horizontal," "left" and "right," "above" and "below," "row" and "column," and the like are used herein only for convenience, and that no fixed or absolute directional or orientational limitations are intended by the use of these words. For example, the devices of this invention can have any desired orientation. If reoriented, different directional or orientational terms may need to be used in their description, but that will not alter their fundamental nature as within the scope and spirit of this invention. Terms like "region" and "subregion" are also used only as generic, relative terms, and other terms may be used for generally similar circuitry. Indeed, these terms may be used interchangeably herein in contexts in which a region/subregion hierarchy is not important.

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Alternatively, devices within the scope of this invention may have regions of programmable logic that are not divided into subregions. Although look-up table logic is employed in the illustrative embodiments shown and described herein, it will be understood that other types of logic may be used instead if desired. For example, sum-of-products logic, such as is the primary example considered in references like Pederson et al. U.S. patent 5,241,224 and Patel et al. U.S. patent 5,371,422 (both of which are hereby incorporated by reference herein in their entireties), may be used instead of look-up table logic.

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The Invention Claimed Is

1. A programmable logic integrated circuit device comprising:

a plurality of regions of programmable logic disposed on the device in a two-dimensional array of intersecting rows and columns of said regions, each of said regions being programmable to perform any of a plurality of logic functions on a plurality of logic region input signals applied to the logic region to produce at least one logic region output signal;

a plurality of interconnection conductors associated with each of the rows and configured to convey signals to, from, and/or between the logic regions in the associated row; and

at least one programmable logic connector respectively associated with each of the interconnection conductors and configured to programmably select any of a plurality of PLC input signals applied to the programmable logic connector for application to the interconnection conductor associated with that programmable logic connector, at least one of the PLC input signals applied to each programmable logic connector being the logic region output signal of a logic region in the row associated with the interconnection conductor that the programmable logic connector applies a signal to, and at least one other of the PLC input signals applied to each programmable logic connector being the logic region output signal of a logic region in another row which is applied to the programmable logic connector substantially directly from the logic region in the other row.

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2. The device defined in claim 1 wherein the other row is adjacent to the row associated with the interconnection conductor that the programmable logic connector applies a signal to.

3. The device defined in claim 1 wherein a third one of the PLC input signals applied to each programmable logic connector is the logic region output signal of a logic region in a third row which is applied to the programmable logic connector substantially directly from the logic region in the third row.

4. The device defined in claim 3 wherein the other row and the third row are both adjacent to, but on opposite sides of, the row associated with the interconnection conductor that the programmable logic connector applies a signal to.

5. The device defined in claim 1 further comprising:

a driver associated with each programmable logic connector and configured to strengthen the signal that the programmable logic connector applies to the associated interconnection conductor.

6. The device defined in claim 5 wherein the driver is a programmably controlled tri-state driver.

7. The device defined in claim 1 wherein each logic region includes:

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combinatorial logic circuitry which is programmable to produce a first intermediate signal which is any of a plurality of logical combinations of the logic region input signals applied to the logic region;

register circuitry configured to produce a second intermediate signal which is the result of registering the first intermediate signal; and

output signal selection circuitry configured to programmably select the logic region output signal from one of the first and second intermediate signals.

8. The device defined in claim 1 wherein each conductor in a subplurality of the interconnection conductors associated with each row extends adjacent a respective different one of a plurality of subsets of the logic regions in that row, the logic regions in each subset being adjacent to one another, and wherein the interconnection conductor associated with each programmable logic connector is one of the conductors in the subplurality.

9. The device defined in claim 8 wherein each programmable logic connector is operatively connected to an endpoint of the associated interconnection conductor.

10. A digital processing system comprising:  
processing circuitry;  
a memory coupled to said processing circuitry; and

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a programmable logic integrated circuit device as defined in claim 1 coupled to the processing circuitry and the memory.

11. A printed circuit board on which is mounted a programmable logic integrated circuit device as defined in claim 1.

12. The printed circuit board defined in claim 11 further comprising:

a memory mounted on the printed circuit board and coupled to the programmable logic integrated circuit device.

13. The printed circuit board defined in claim 11 further comprising:

processing circuitry mounted on the printed circuit board and coupled to the programmable logic integrated circuit device.

14. A programmable logic integrated circuit device comprising:

a plurality of regions of programmable logic disposed on the device in a two-dimensional array of intersecting rows and columns of said regions, each of said regions being programmable to perform any of a plurality of logic functions on a plurality of logic region input signals applied to the logic region to produce at least one logic region output signal;

a plurality of interconnection conductors associated with each of the rows and configured to convey signals to, from, and/or between the logic regions in the associated row; and

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programmable logic connector circuitry associated with each of the logic regions and configured to programmably select a signal applied to one of a plurality of PLC input terminals of the programmable logic connector circuitry for application to the associated logic region as a logic region input signal, at least a first one of the PLC input terminals being connected to an interconnection conductor associated with the row that includes that logic region, and at least a second one of the PLC input terminals being connected to an interconnection conductor associated with another row that is adjacent to the row that includes that logic region.

15. The device defined in claim 14 further comprising:

second programmable logic connector circuitry associated with each of the logic regions and configured to programmably select a signal applied to one of a plurality of second PLC input terminals of the second programmable logic connector circuitry for application to the associated logic region as another logic region input signal, at least a first one of the second PLC input terminals being connected to an interconnection conductor associated with the row that includes that logic region, and at least a second one of the second PLC input terminals being connected to an interconnection conductor associated with a third row that is adjacent to the row that includes that logic region.

16. The device defined in claim 14 wherein the PLC input terminals of the programmable logic connector circuitry associated with each of the logic

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regions are connected to only a subset of the interconnection conductors associated with the row that includes that logic region and the row adjacent to the row that includes that logic region.

17. The device defined in claim 15 wherein the PLC input terminals of the programmable logic connector circuitry associated with each of the logic regions are connected to only a subset of the interconnection conductors associated with the row that includes that logic region and the row adjacent to the row that includes that logic region, and wherein the second PLC input terminals of the second programmable logic connector circuitry associated with each of logic regions are connected to only a second subset of the interconnection conductors associated with the row that includes that logic region and the third row that is adjacent to the row that includes that logic region.

18. A programmable logic integrated circuit device comprising:

a row of regions of programmable logic, each being programmable to perform any of a plurality of logic functions on a plurality of logic region input signals applied to the logic region to produce at least one logic region output signal;

a first conductor associated with each of the logic regions and extending from the associated logic region adjacent a first subplurality of others of the logic regions that are adjacent to the associated logic region on a first side of the associated logic region;

a second conductor associated with each of the logic regions and extending from the associated

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logic region adjacent a second subplurality of still others of the logic regions that are adjacent to the associated logic region on a second side of the associated logic region;

first programmable logic connector circuitry associated with each of the logic regions and configured to selectively apply the logic region output signal of the associated logic region to either or both of the first and second conductors associated with that logic region; and

second programmable logic connector circuitry associated with at least some of the logic regions that each of the first and second conductors is adjacent to and configured to selectively apply a signal on that first or second conductor to the associated logic regions as a logic region input signal.

19. The device defined in claim 18 wherein each of the first subpluralities includes approximately a same first number of the logic regions.

20. The device defined in claim 18 wherein each of the second subpluralities includes approximately a same second number of the logic region.

21. The device defined in claim 18 wherein each of the first and second subpluralities includes approximately a same number of the logic regions.

22. The device defined in claim 18 wherein each of the logic regions is programmable to produce a plurality of logic region output signals, and wherein the first programmable logic connector circuitry

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associated with each of the logic regions is further configured to alternatively selectively apply different ones of the logic region output signals of the associated logic region to the first and second conductors associated with that logic region.

23. The device defined in claim 22 wherein the first programmable logic connector circuitry associated with each of the logic regions is still further configured to alternatively selectively apply any of multiple ones of the logic region output signals of the associated logic region to either of the first and second conductors associated with that logic region.

24. The device defined in claim 18 wherein the second programmable logic circuitry is associated with all of the logic regions that each of the first and second conductors is adjacent to.

25. The device defined in claim 18 wherein the row is one of a plurality of similarly constructed, parallel rows, and wherein the first programmable logic connector circuitry associated with each of the logic regions is further configured to alternatively selectively apply to either or both of the first and second conductors associated with that logic region a logic region output signal from another logic region in a row adjacent to the row that includes that logic region.

26. The device defined in claim 25 wherein the another logic region associated with each logic region is substantially aligned with the logic region

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in a column of logic regions that is substantially perpendicular to the rows of logic regions.

27. A digital processing system comprising:  
processing circuitry;  
a memory coupled to said processing  
circuitry; and

a programmable logic integrated circuit  
device as defined in claim 18 coupled to the processing  
circuitry and the memory.

28. A printed circuit board on which is  
mounted a programmable logic integrated circuit device  
as defined in claim 18.

29. The printed circuit board defined in  
claim 28 further comprising:

a memory mounted on the printed circuit  
board and coupled to the programmable logic integrated  
circuit device.

30. The printed circuit board defined in  
claim 28 further comprising:

processing circuitry mounted on the  
printed circuit board and coupled to the programmable  
logic integrated circuit device.

31. A programmable logic integrated circuit  
device comprising:

a plurality of regions of programmable  
logic disposed on the device in a two-dimensional array  
of intersecting rows and columns of such regions, each  
of the regions being programmable to perform any of a  
plurality of logic functions on a plurality of logic

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region input signals applied to the logic region to produce at least one logic region output signal;

a plurality of interconnection conductors associated with each of the rows and configured to convey signals to, from, and/or between the logic regions in the associated row;

a plurality of region-feeding conductors associated with each of the logic regions and configured to bring signals to the associated logic region as at least some of the logic region input signals of the associated logic region;

first programmable logic connector circuitry associated with each of the logic regions and configured to selectively apply to the region-feeding conductors associated with that logic region signals from the interconnection conductors associated with the row that includes that logic region; and

second programmable logic connector circuitry associated with each of the logic regions and configured to selectively apply signals from the region-feeding conductors associated with that logic region to the region-feeding conductors that are associated with another adjacent logic region in the column that includes that logic region.

32. The device defined in claim 31 further comprising:

third programmable logic connector circuitry associated with each of the logic regions and configured to selectively apply signals from the region-feeding conductors associated with that logic region to the region-feeding conductors that are associated with a further adjacent logic region in the column that includes that logic region but on the other

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side of that logic region from the another logic region associated with that logic region.

33. The device defined in claim 31 further comprising:

a local feedback conductor associated with each of the logic regions and configured to receive the logic region output signal of the associated logic region for application to the associated logic region as at least one of the logic region input signals of the associated logic region; and

third programmable logic connector circuitry associated with each of the logic regions and configured to selectively apply a signal from the local feedback conductor that is associated with that logic region to at least one of the region-feeding conductors that are associated with another adjacent logic region in the column that includes that logic region.

34. The device defined in claim 33 further comprising:

fourth programmable logic connector circuitry associated with each of the logic regions and configured to selectively apply a signal from the local feedback conductor that is associated with that logic region to at least one of the region-feeding conductors that are associated with a further logic region in the column that includes that logic region but on the other side of that logic region from the another logic region associated with that logic region.

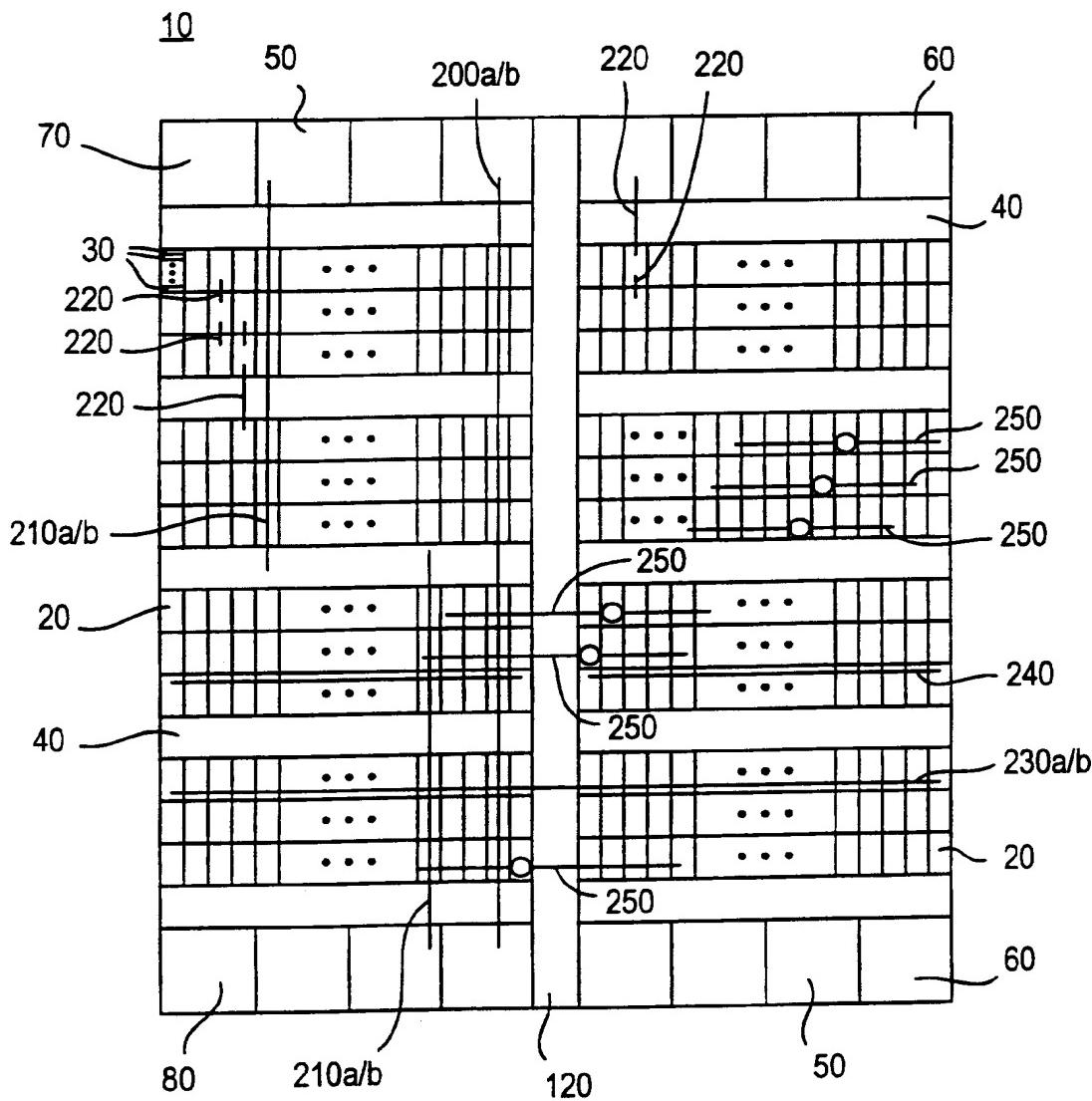


FIG. 1

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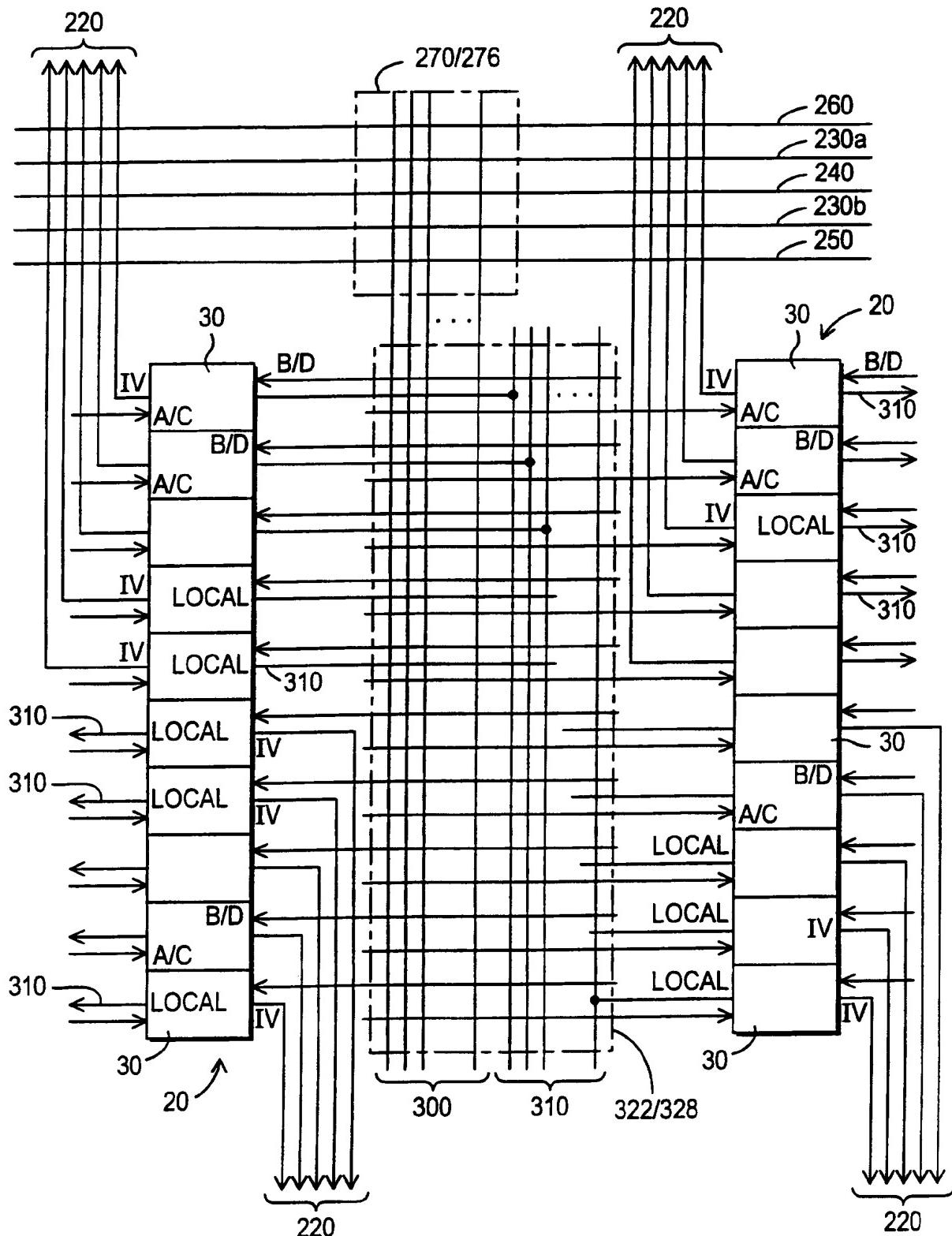
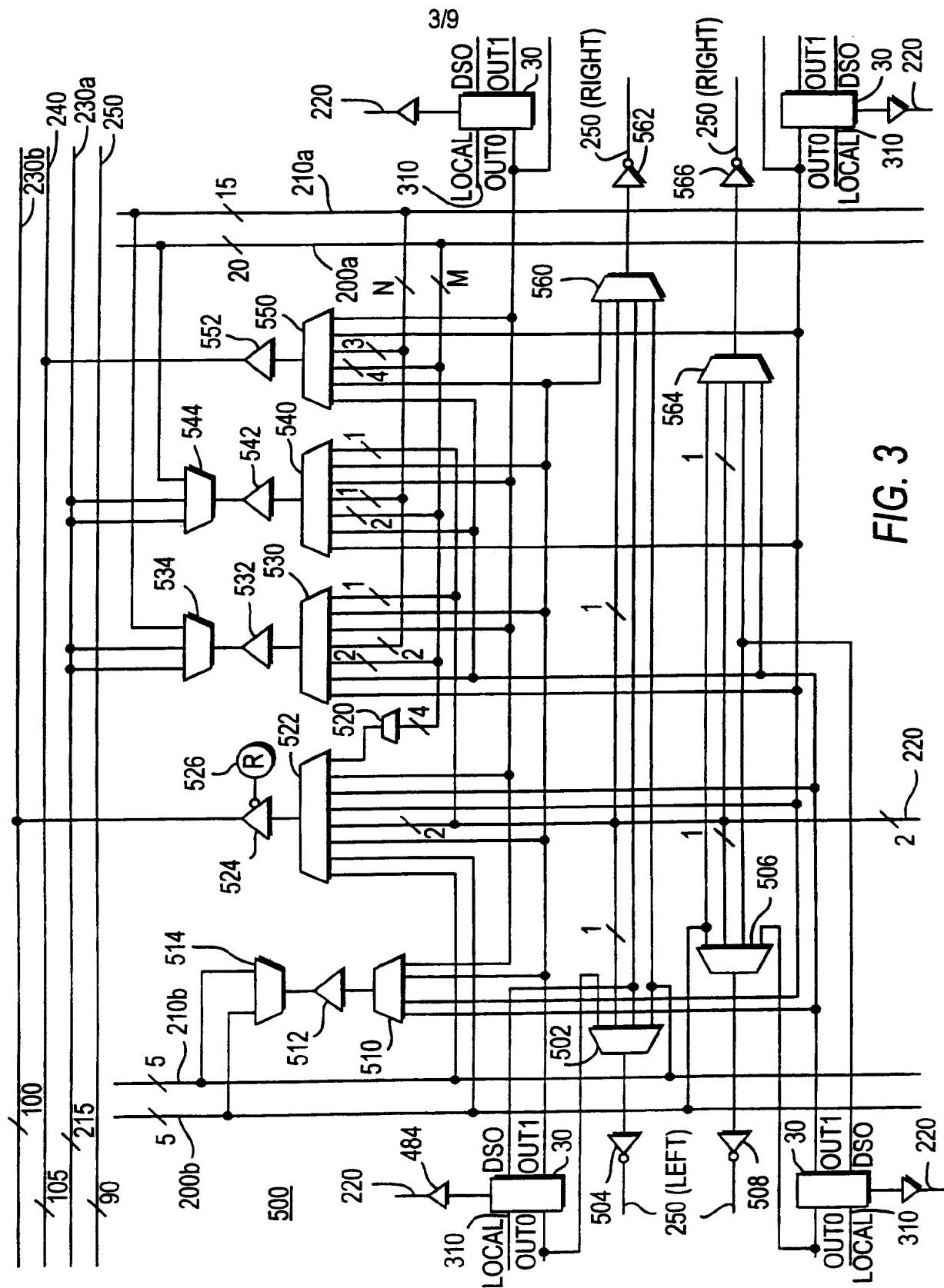


FIG. 2



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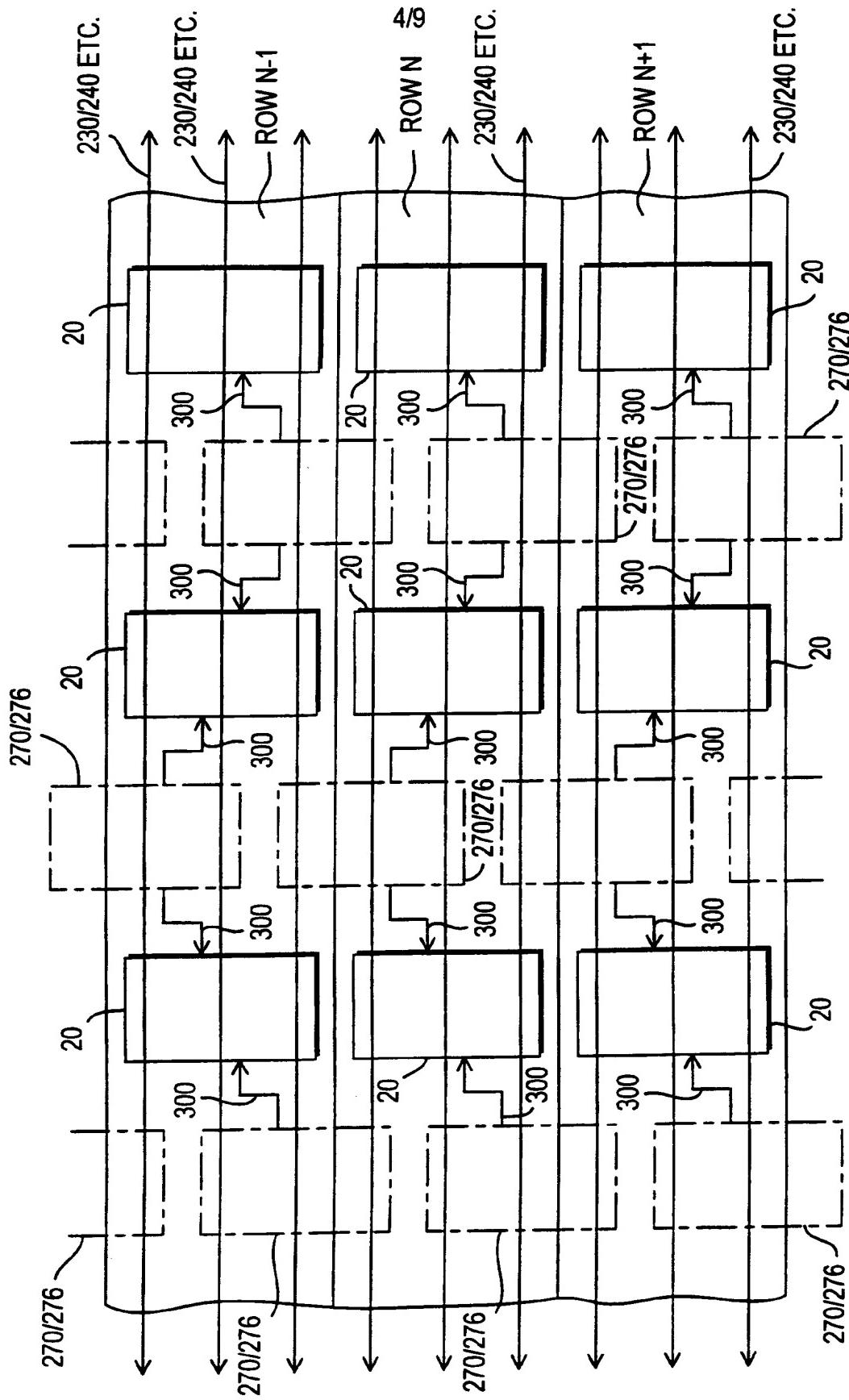


FIG. 4

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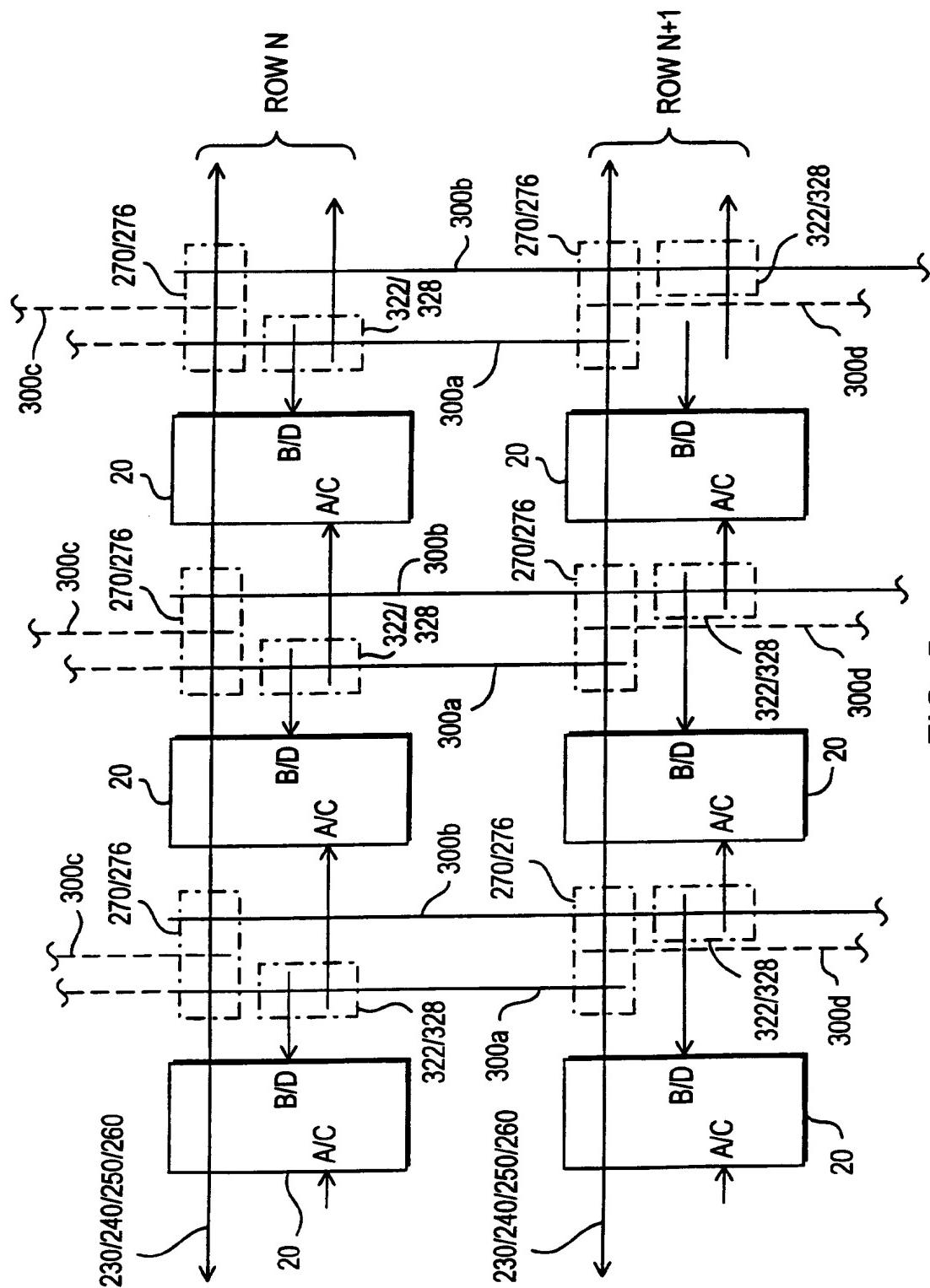


FIG. 5

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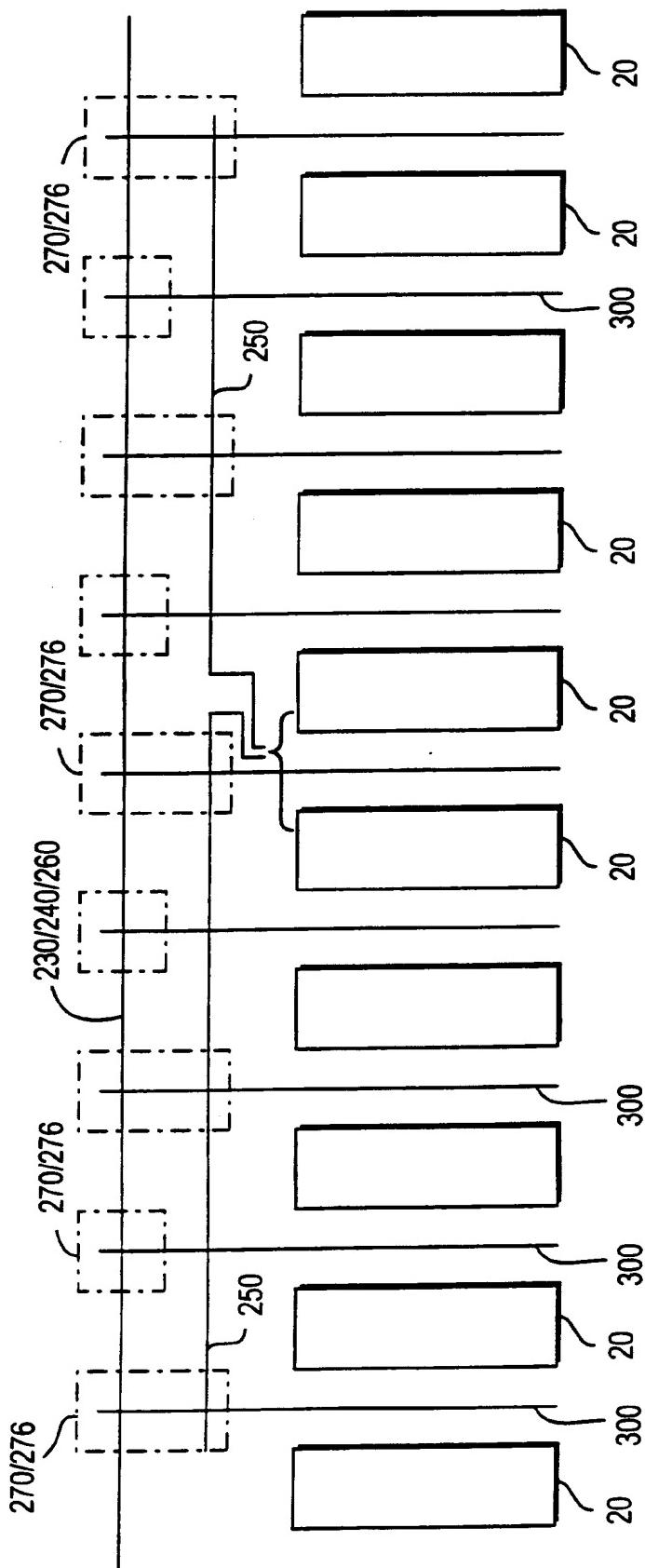


FIG. 6

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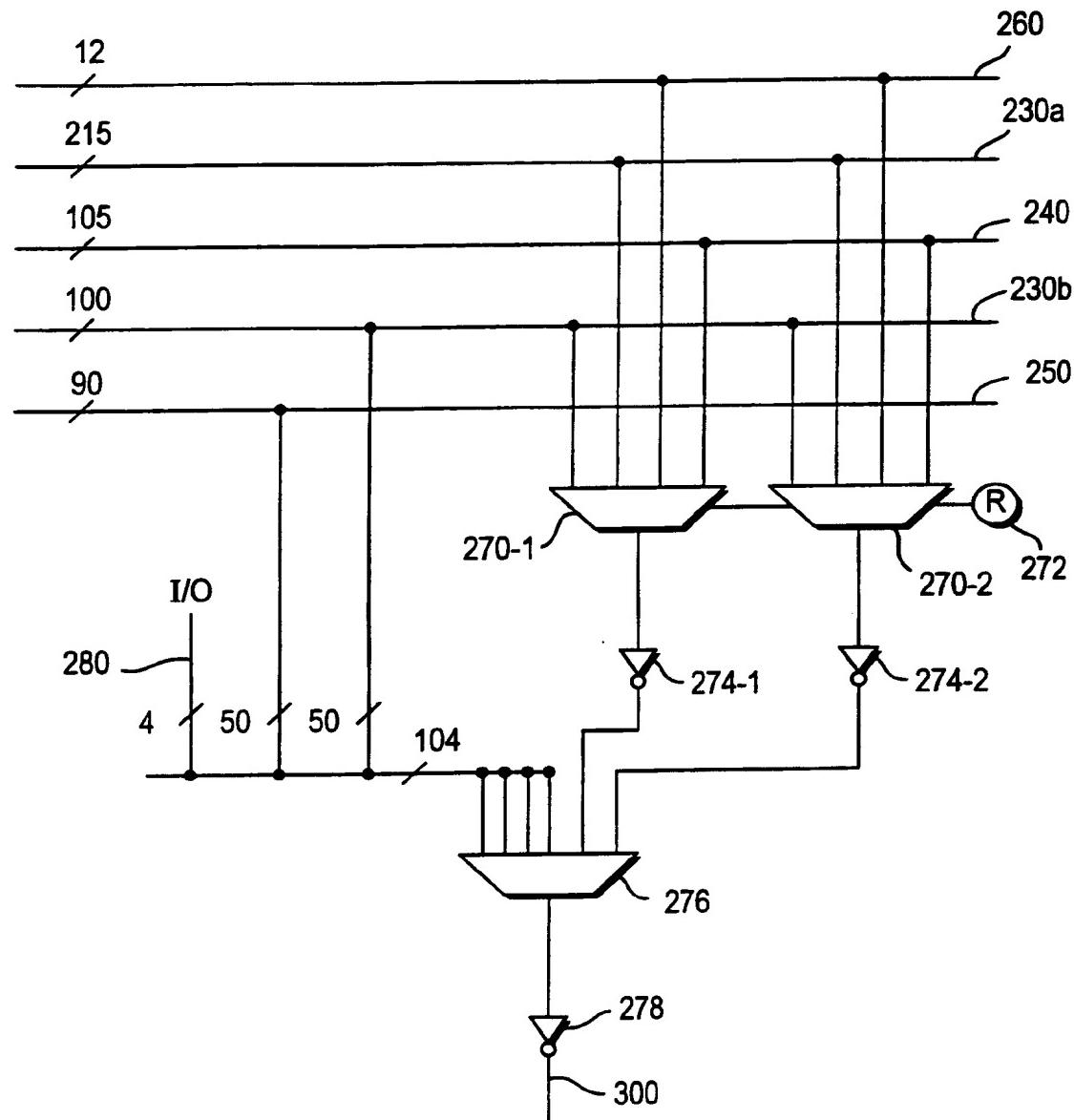


FIG. 7

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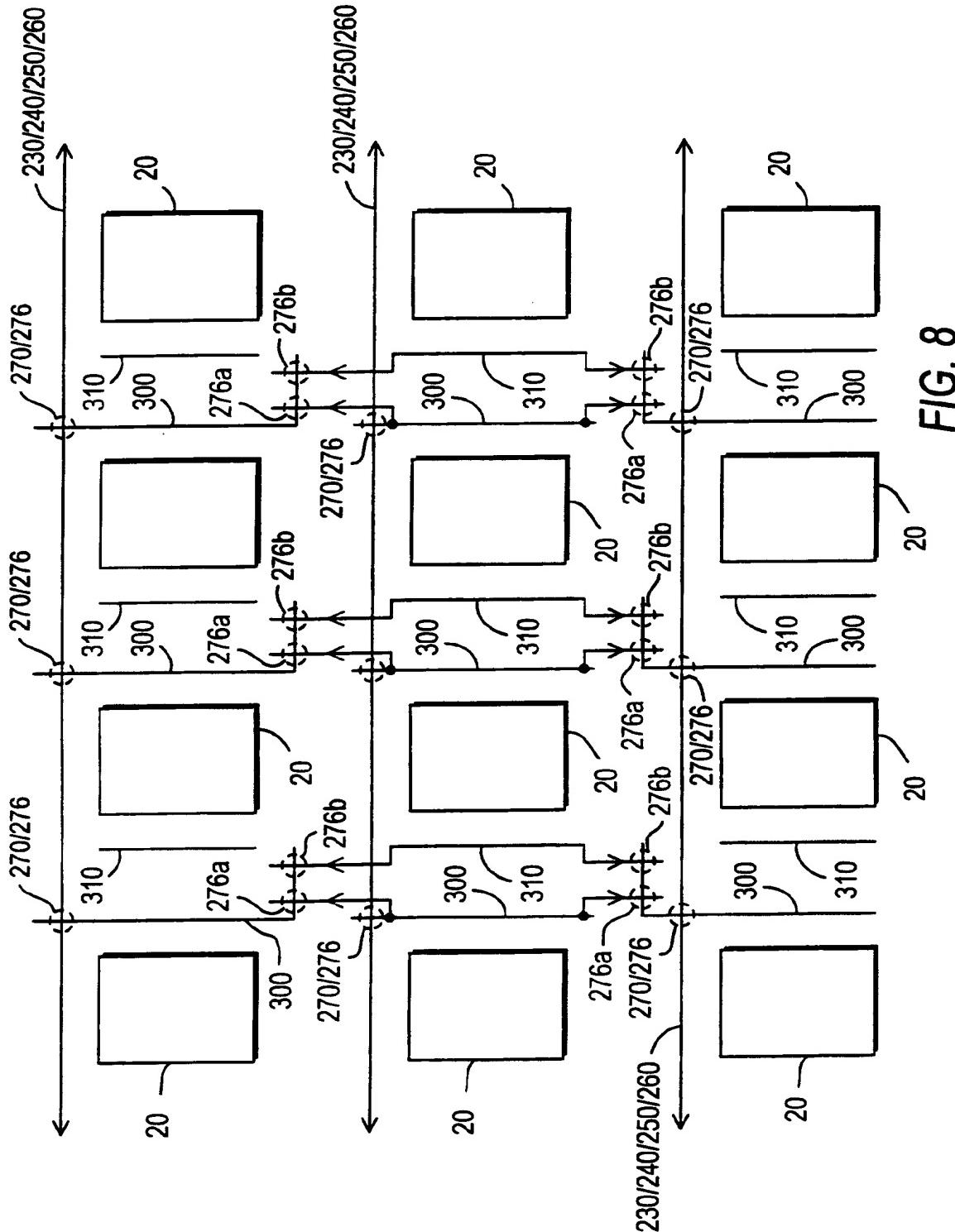


FIG. 8

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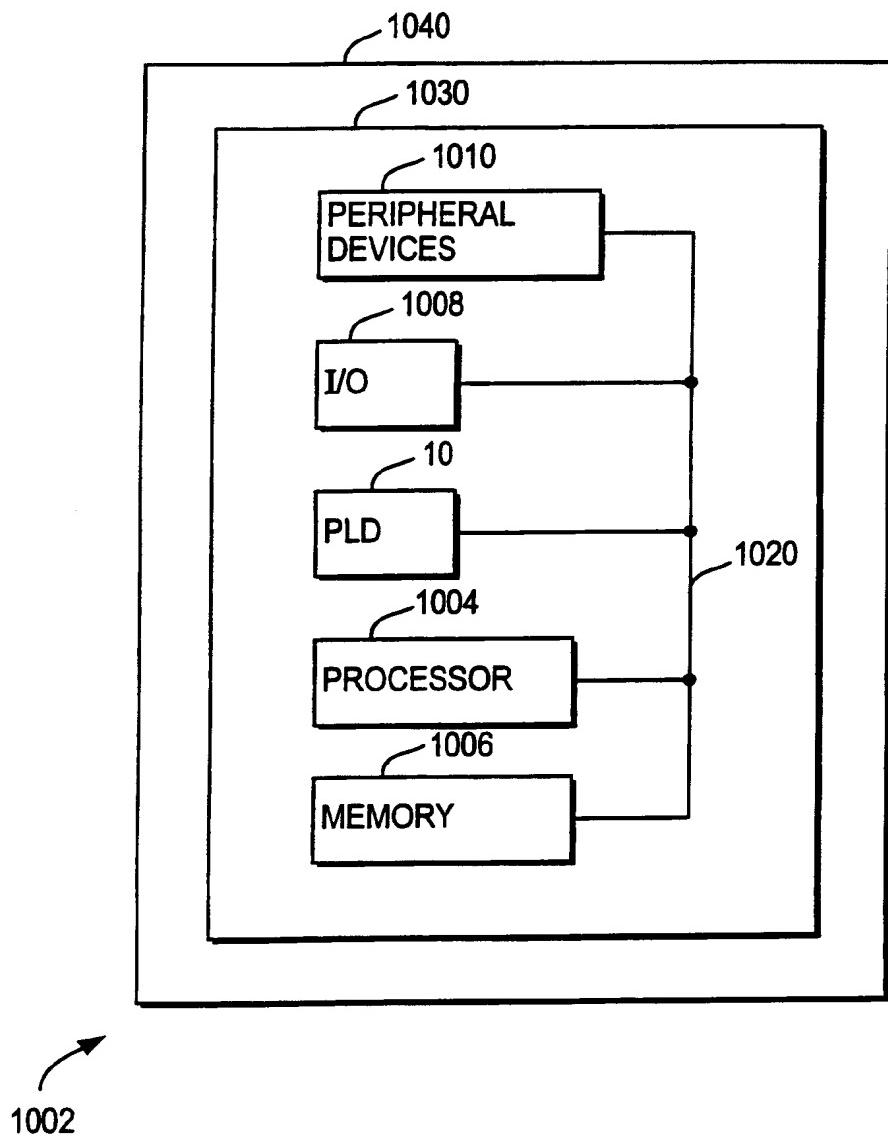


FIG. 9

# INTERNATIONAL SEARCH REPORT

National Application No

PCT/US 00/05488

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 H03K19/177 H03K19/173

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 H03K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages                                                                               | Relevant to claim No. |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search

Date of mailing of the international search report

15 June 2000

23/06/2000

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**INTERNATIONAL SEARCH REPORT**

National Application No

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**C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category | Citation of document, with indication, where appropriate, of the relevant passages                                                                           | Relevant to claim No. |
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